The ISM seen at unprecedented resolution

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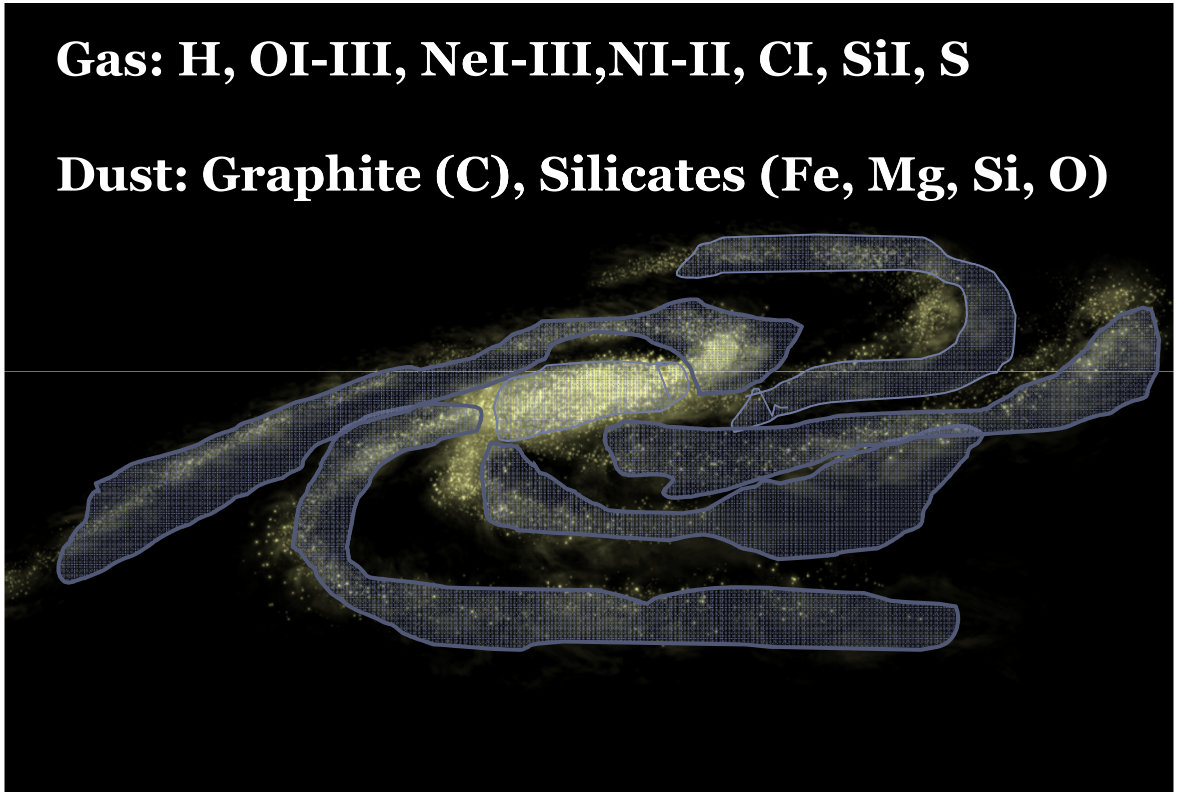
Interstellar medium (dust and gas)

Stellar evolution

Metals
(AGB and RGB stars,SN)

ISM
(reservoir for stars
and planets)

Cold phase


Gas: H, OI-III, NeI-III,NI-II, CI, SiI, S
Dust: Graphite (C), Silicates (Fe, Mg, Si, O)

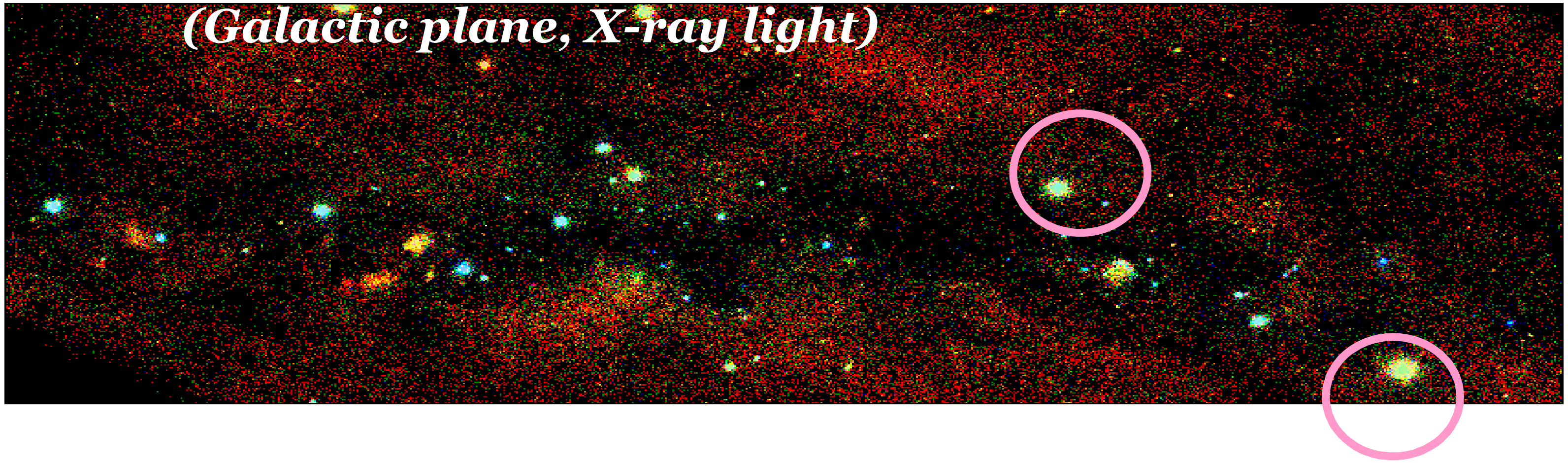
Why study the ISM in the X-rays

- Gas phase: N, O, Fe, Ne, Mg, Si
- Dust: O (0.54keV), Fe (0.7-7.1keV), Mg (1.3keV), Si(1.87keV)→ all constituents of silicates!
- Dust: prominent iron features (Fe L and K-edge), absent in IR band
- Element depletion is straightforward to determine
- both scattering and absorption can be simultaneously studied
- XRB are used as background light → mapping all the galactic plane

How to proceed?

- Dust and gas absorb the X-ray radiation →
  - High resolution X-ray spectroscopy
    - *e.g. Juett+03, CygX-2 (EC+05), Crab (Kaastra+09), CygX-1 (Lee+09), GS 1826-238, (Pinto+10)*
  - Laboratory measurements to sample all likely species present in the ISM
    - *(e.g. Lee+05,09, deVries, EC+11 in prep)*
- Dust scatters the X-ray radiation →
  - Imaging spectroscopy of dust scattering halos
    - *e.g. Cyg X-2 (EC+05), GX5-1 (Smith, Dame, EC+06), Tiengo+10*

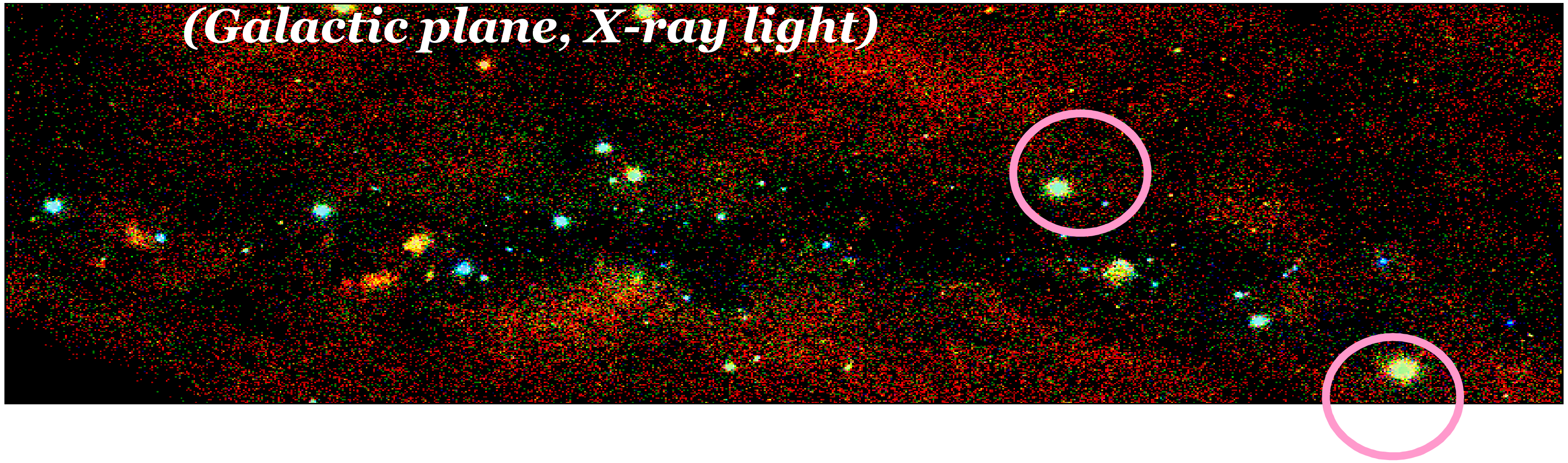
Dust scattering in a nutshell



- Small scattering angle
- Halo extension: several arcmin.
- Halo energy: < 2 keV but in exceptional cases up to 6 keV

- In one observation absorption+scattering

Dust scattering

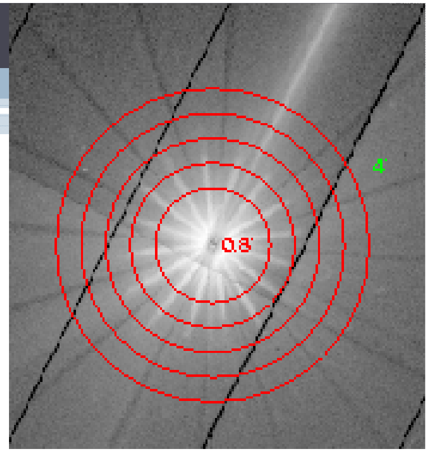


Methods:

• surface brightness profile at one energy
→ constraints on dust distribution on the line of sight
& grain size distribution

•spectrum at one distance (normalized by the source spectrum)
→ Dust contribution can be isolated (i.e. gas does not scatter)
→ Chemistry of the dust

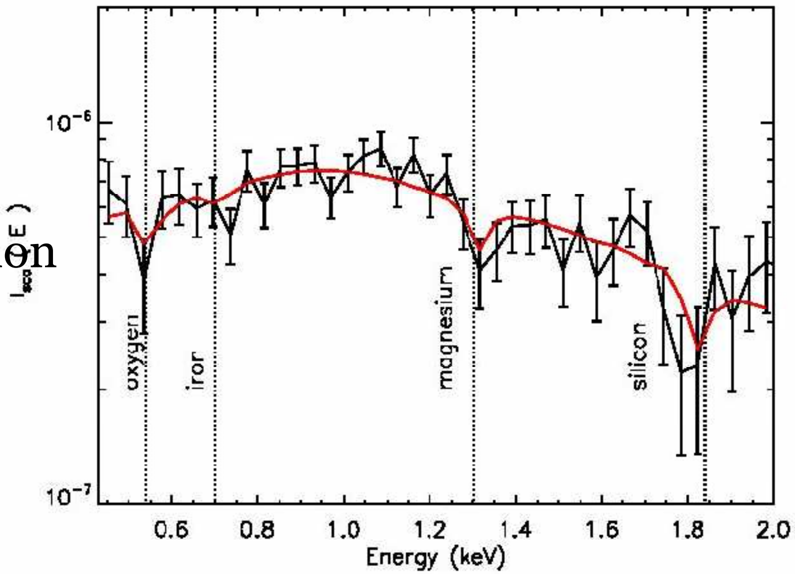
Scattering: the case of Cyg X-2



• spectrum at one distance (normalized by the source spectrum)
→ Dust contribution can be isolated (i.e. gas does not scatter)
→Chemistry of the dust

• First evidence of the dust spectroscopical signatures in Cyg X-2 (O, Mg, Si)
→ Mg:Fe=5:2 (→ Fe-poor silicates!)

→Scattering by dust (spectroscopy+imaging) can provide a precious tool to study distribution and composition of dust grains.



(Cyg X-2, Costantini+05)

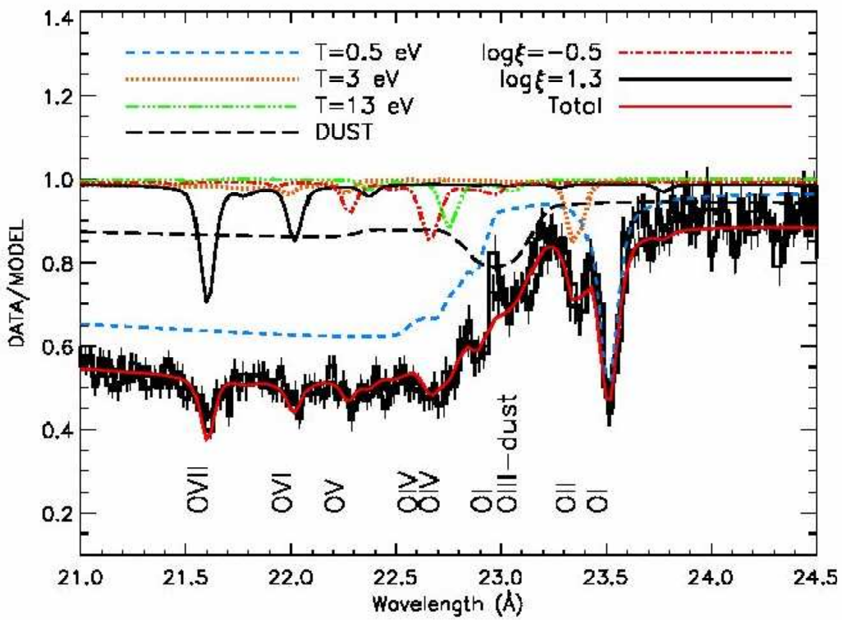
Absorption

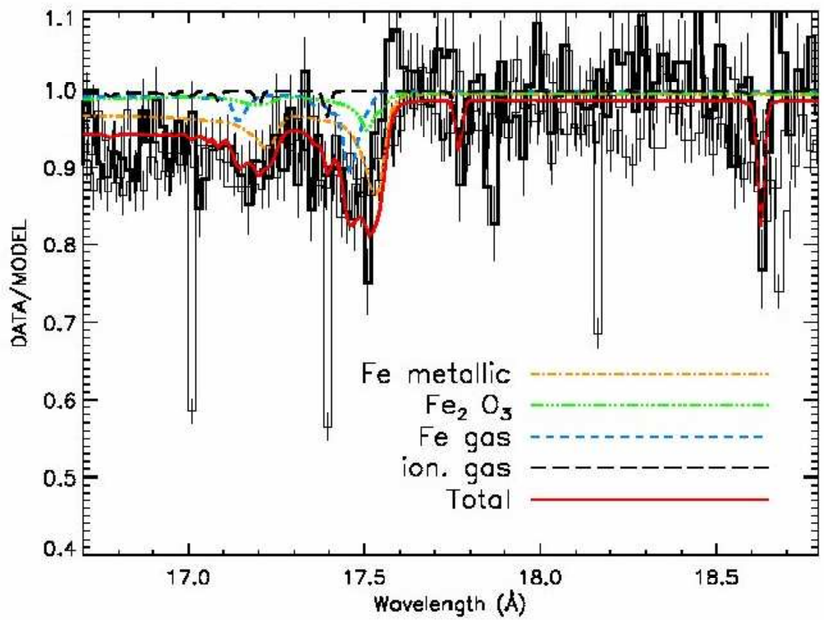
- optimal view of O and Fe

→ Fe is 90% and O 20% in dust

→ Mg-rich silicates (rather than Fe-rich)

→ Metallic iron + traces of oxydes

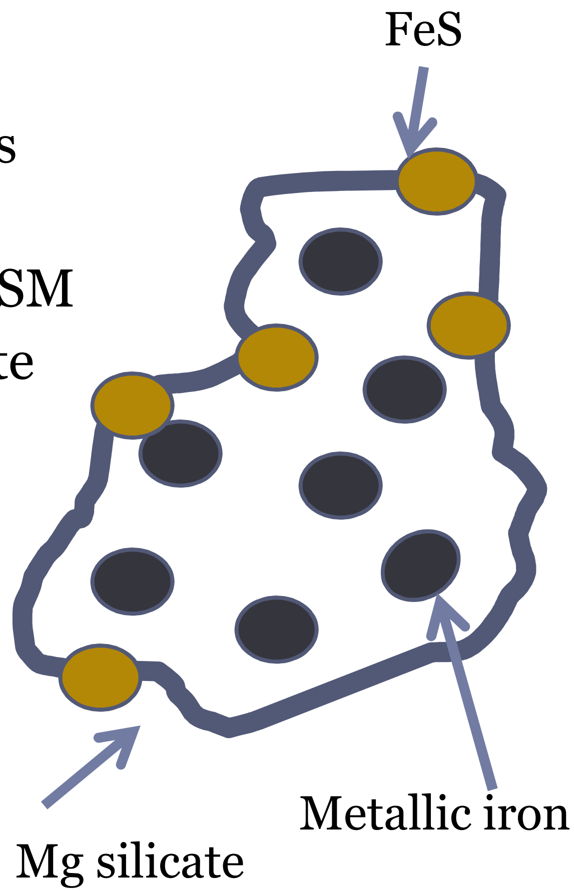


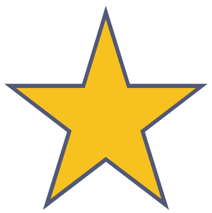


(Costantini+11 in prep.)

Are we detecting GEMS?

GEMS= glass with embedded metal and sulphides
(e.g. Bradley+04)
interplanetary origin, but some of them do have ISM origin → invoked as prototype of a classical silicate





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Crystal
olivine, pyroxene
With Mg → Cosmic rays+radiation → Glassy structure + FeS →

→ Sulfur evaporation → GEMS

Implications

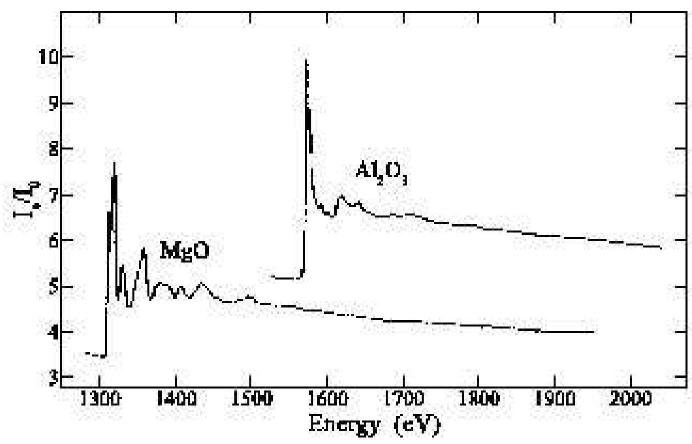
- Status of the art: silicates have Mg:Fe~1, mainly based on the modeling of the 10micron emission feature *(Li&Draine 01)*
- Alternatively: Mg:Fe~5:2 *(Min+07,EC+05)* → room for a "GEMS" composition

X-rays can be (and become even more) a powerful and competitive tool to solve crucial issues on ISM

Absorption near the edge

XAFS: oscillatory absorption features due to the interaction of the photoelectron wave with the others from nearby atoms.

XANES (Xray Absorption Near Edge Structure)
+ EXAFS (Extended X-ray absorption fine structure)



What do we learn from XAFS?

Energy of the peaks
→ Electron distance from the nucleus

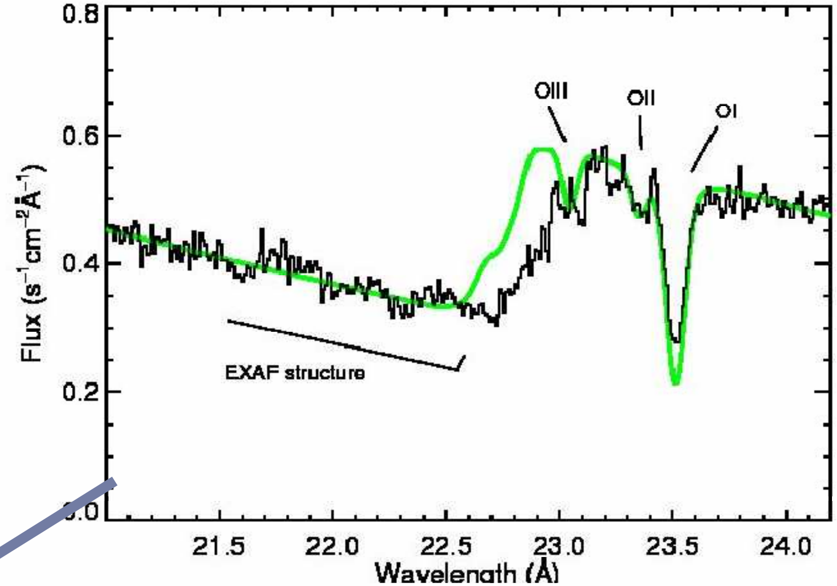
Intensity and number of the peaks
→ Complexity of the compound

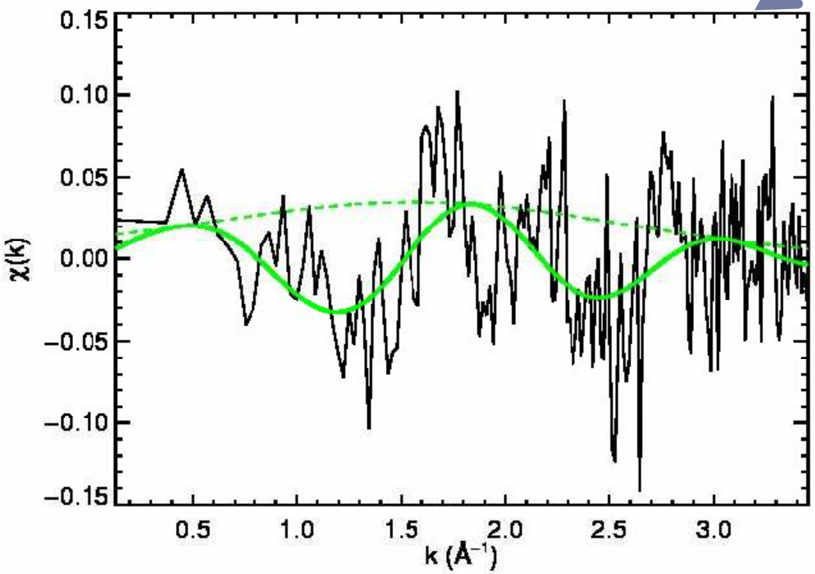
Sco X-1

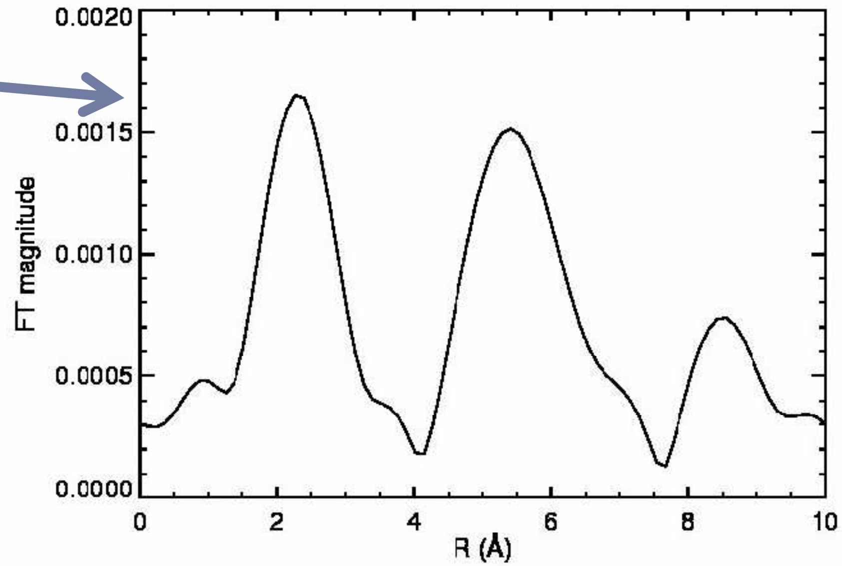
RGS observations with tot exp=73ks
Spectrum cleaned from bad pixels

EXAFS detected for the first time
→Tentative identification with ice

→ Do we have a complete data base?



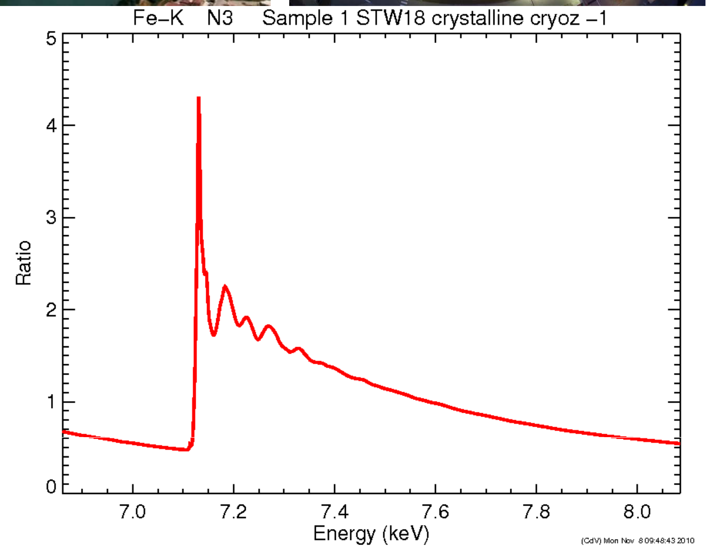




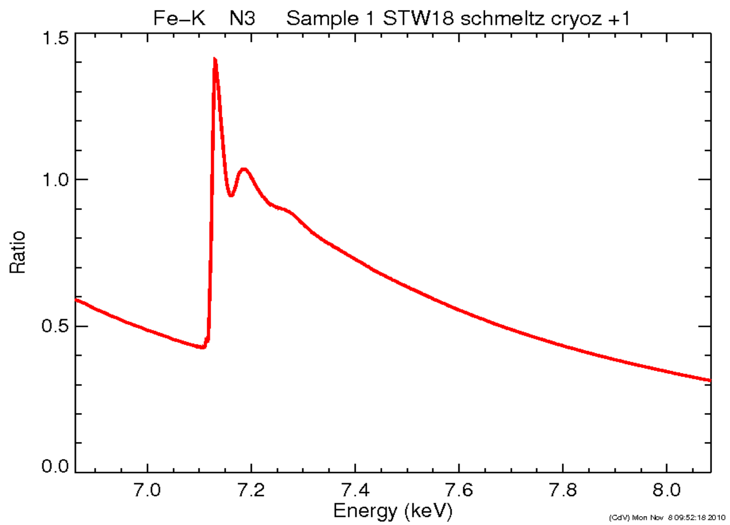
(deVries & Costantini 2009)

Lab measurements

- New laboratory measurments (syncrotron+electron-microscope)
  - Focusing on:
  - silicates
    - e.g. different Mg:Fe ratios in silicates, sulfates etc
  - amorphous compounds
  - Sampling of the whole X-ray spectrum for each species (O, FeL, FeK, Mg, Si and S)



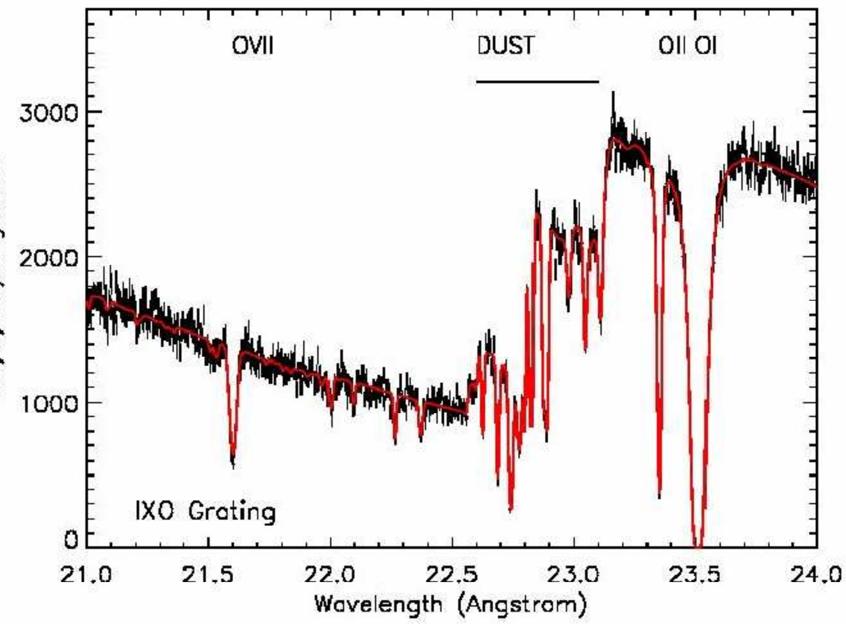
First measurements → Fe K edge @7.1 keV
Significant difference between amorphous and crystalline form of the same compound
The resolution of the lab measurements is 0.8-3 eV

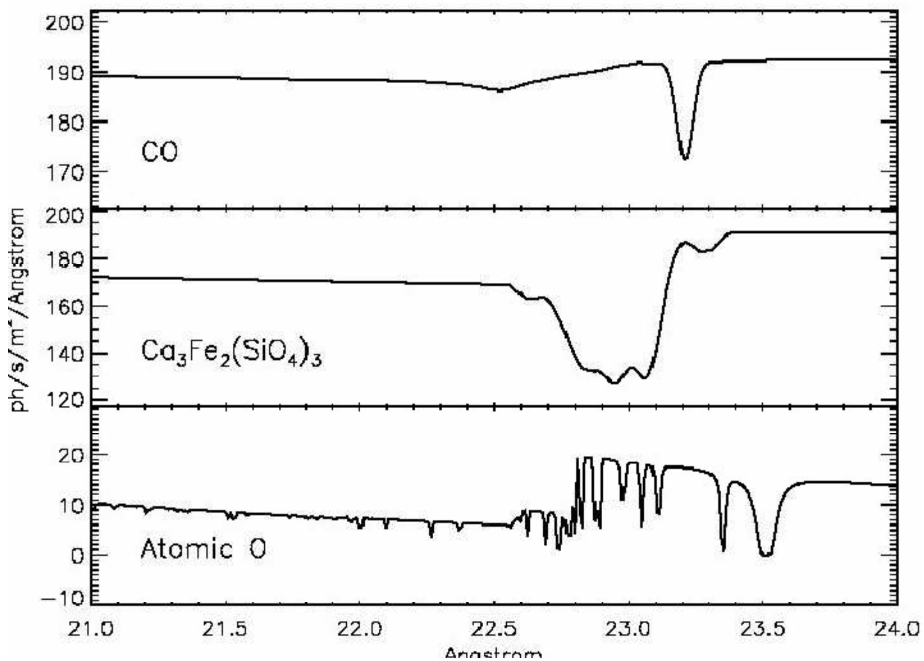


This work is complementary to the xafs.org data base (e.g. Lee+09)

The oxygen edge (IXO grating)

(*Based on Pinto+10 model*)





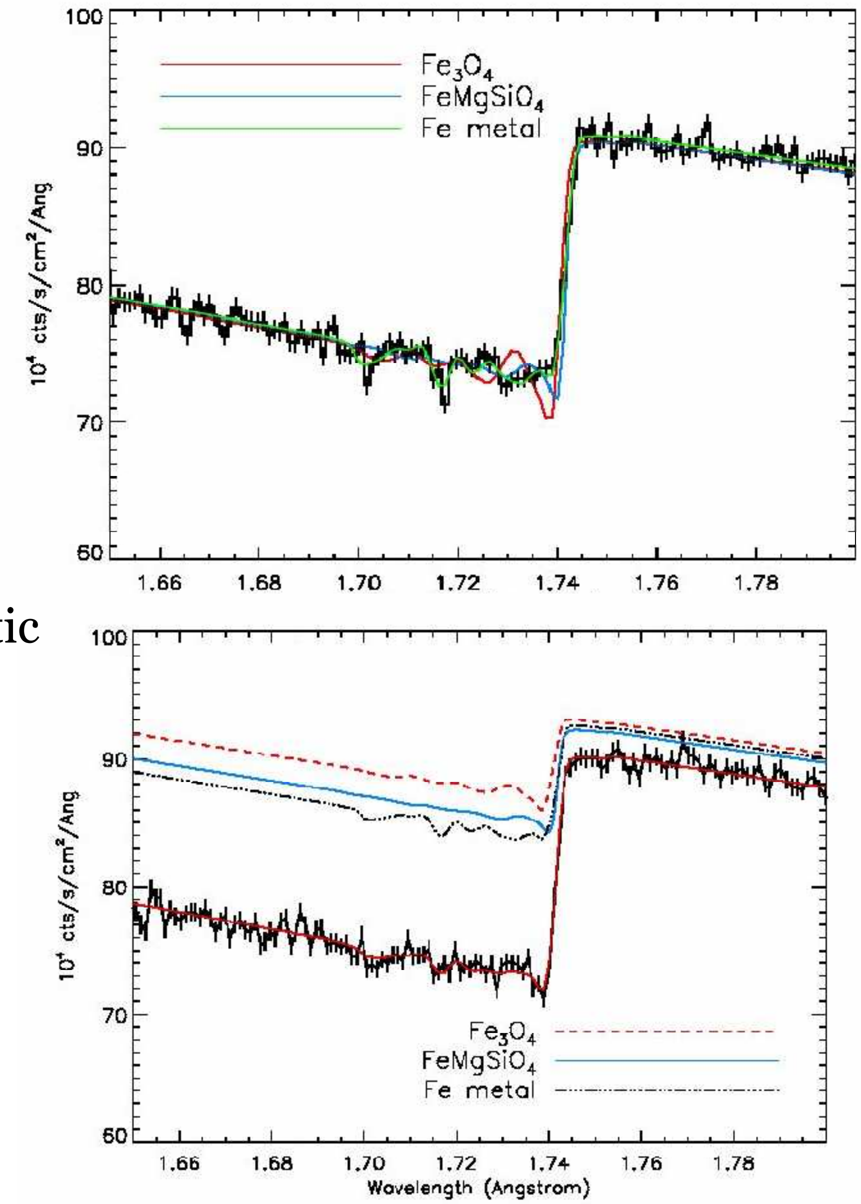
- Absorption by dust compounds produces broader and smeared features. Depending on the electrical field in the compound, the features show different shapes, energy shift, and most of all a different set of EXAFS.
- It is crucial to disentangle the contribution of atomic gas.

Iron K edge

Only absorbed sources (N_H>8x10^{22}cm^{-2})

→Handful of galactic sources

• Important to probe metallicity close to The Galactic Center.
• Template for highly obscured extragalactic objects

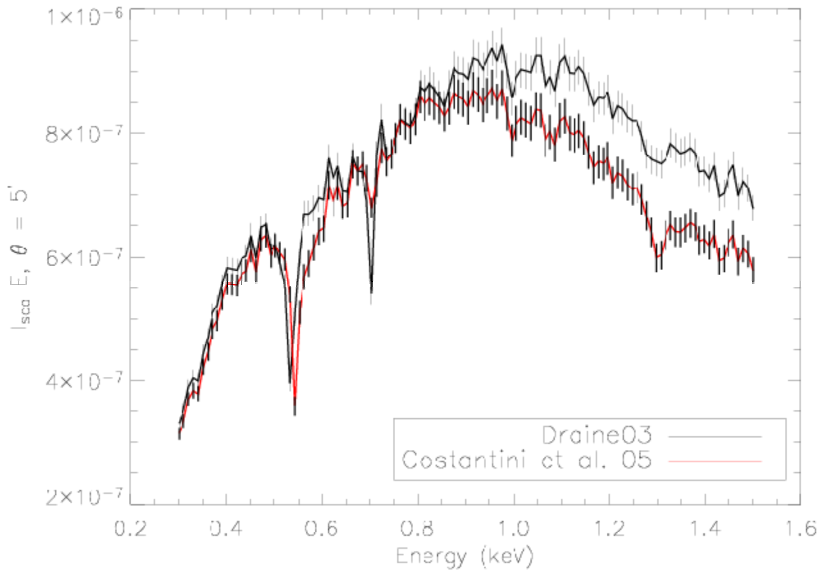


IXO imaging+spectroscopy

The IXO outer field of view (to 5'x5') view of dust.

The scattering halos extend to several arcmin
Faint emission (integrated flux ≤10^{11} cgs)

→ Differentiation among different models



Conclusions

- X-rays have a great potential in the study of the ISM :
  - Complementary to IR
  - Dust features shows up in different ways (e.g. scattering & absorption)
- The breakthrough can be achieved only by mean of improved spectroscopical capabilities (both in the soft and hard band).